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IN THE UNITED STATES PATENT AND TRADEMARK OFFICE

In re Application of

Ronald H. KNAPP

Serial No. 10/804,203

Filed: March 19, 2004

Art Unit: 2878

Examiner: Monbleau, Davienne, N.

For: FIBER OPTIC SENSORS FOR COMPOSITE PRESSURE TANKS

DECLARATION

I, Ronald H. Knapp, Ph.D., P.E., declare:

a. I am the inventor of the fiber optics sensors in composite pressure tanks described and claimed in Patent Application 10/804,203 filed March 19, 2004.

b. My invention as described and claimed in the above identified patent application is the bonding of a helically wound inexpensive telephone grade fiber from a neck to a closed end of an aluminum impervious tank liner and back to the neck, forming cross-over points with the optical fiber. The two ends of the optical fiber are exposed and connected to at the neck of the liner for connection to an inexpensive laser light source and an inexpensive light intensity sensor.

The tank liner provides the requisite gas impermeability. The optical fiber is covered by a conventional composite layer of wound tape and matrix material (e.g. epoxy), which provides the requisite strength to prevent tank liner failure.

PAGE 2/7 * RCVD AT 11/21/2008 3:19:15 PM [Eastern Standard Time] * SVR:USPTO-EFXRF-6/21 * DNIS:2738300 * CSID:703 448 7397 * DURATION (mm-ss):02-34

c. In my invention, the cross-over points of the telephone grade optical fiber are squeezed between the expanding tank liner and against the strength providing composite layer as the interior of the tank liner is pressurized and the tank liner expands against the strength providing layer.

d. The practicality of this invention was demonstrated in the manufacturing methods that were developed. The overall success of the design, manufacturing and testing of five prototype composite tanks suggest that the invention is commercially viable.

e. Novel apparatus that I developed are summarized and enumerated below.

1. A low-cost, telecommunication single-mode optical fiber (e.g. Corning SMF-28) can function as an effective sensor when secured to the wall of a composite wrapped tank liner and squeezed between the tank liner and the composite wrap. An inexpensive, hand-held light source and power meter is all that is required to monitor the structural health of a tank.

2. The fiber sensor is contra-helically wrapped around an aluminum liner. The number of pinch points (fiber crossings) can be adjusted to control through light diminution by the number of helical wraps.

3. By preassembling and securing the fiber sensor on the aluminum liner, the tank can be handled and wound with a filament wrap using current manufacturing techniques.

4. Pinch points where the fiber sensor crosses itself can be filled with an adhesive material that regulates light power loss across the points. The effect of isolating the pinch points, bedding the points with a soft material (polyurethane) or bedding the points with a hard material (epoxy) has been demonstrated. Isolation provides the largest reduced light

transmission signals although nonlinear, and epoxy provides the smallest, although desired linear, signal.

5. A simple, economical method of coating the fiber with a bonding material (polyurethane or epoxy) while it is applied to the tank liner was developed.

6. A new optical connector that is about half the size of a commercial connector was developed and tested. Its small size helps to reduce mechanical damage to the connector when handling of the tank, it also made it possible to locate the connector on the valve stem of the tank. The connector adapts to existing ST-type optiware. To ensure that optical readings are repeatable, the connector uses a polarized connection so that the angular position of mating ferrules is maintained.

f. The fiber is precoated with epoxy, polyurethane or other suitable bonding material for winding onto the tank. The coated fiber would be kept in a tacky, uncured state at low temperature until ready for application to the tank liner. After winding the fiber onto the tank, the polyurethane is cured thermally or by use of ultra-violet (UV) light. Assembly would proceed by first attaching a connector to the valve stem using a rapid cure adhesive. One or more layers would be helically wrapped onto the aluminum linear in a winding machine similar to the procedure depicted in Fig. 2-11 from the patent application, attached hereto as Applicant's Exhibit 1. The second connector then would be attached to the valve stem, the cylindrical portion of the tank would be wrapped with shrink tape. Heat is applied to the shrink tape which has the dual effect of curing the bonding agent while providing pressure to hold the fiber in tight contact with the liner.

g. The purpose of the squeezing optical fiber microbend sensor is to simulate the hydrostatic volumetric test required by the U.S. Department of Transportation for all composite

tanks. If the fiber sensor could replace the hydrostatic test, the tanks could be tested in-situ at low cost and with no loss of use of the tank. Moreover, in-situ testing could be done more frequently than required by the DOT which could lead to extending the useful service life of composite tanks.

h. The fiber sensor must be able to reveal a residual change of light power following pressurization to the rated tank pressure that in normalized form agrees numerically with residual tank volume change. All of the tanks tested demonstrated this capability, but the Tank with polyurcthane-coated fiber followed by the Tank with epoxy-filled fiber performed best.

i. The technical feasibility of the invention has been successfully demonstrated. The economics of producing and installing the fiber sensor undoubtedly will require further effort. In particular, mass production and installation issues of connector components will be needed before commercialization.

j. The fiber is pulled through a bath of the adhesive such as polyurethane. The polyurethane coated fiber is wrapped on the aluminum liner and the polyurethane is cured with heat or UV light and pressure from shrink tape.

k. The adhesive coating secures the fiber to the tank and uniquely protects the otherwise fragile fiber while handling.

l. The new process does not have to change traditional liner handling or composite winding in the existing manufacturing process.

m. The coated fiber is easily applied, robust, easily handled and installed with a standard fiber winder without changes to the existing tank manufacturing process.

n. In my patent application, Figure 5-26, attached hereto as Applicant's Exhibit 2, shows the linear relationship of fiber through light power loss and measured volume change with respect to internal pressure increases.

o. Every cross-over pinch point diminishes light conductivity of the fiber a little bit as the volume increase of the tank inside the fiber and the strengthening wrap squeezes the fiber and cross-over pinch points between the liner and the strengthening composite wrap.

p. The liner response using an inexpensive addition to a standard tank construction and an inexpensive light source and light intensity sensor is a new and unobvious invention. It allows gas filled composite tanks in aircraft for inflation of escape ramps and rafts to be checked for structural integrity without removing the tanks from the aircraft.

q. The invention also allows SCBA or SCUBA tanks to be checked and certified periodically for pressure retention by dive shops using a compact and inexpensive light source and light intensity sensor.

r. The two patents cited by the examiner would not have made the invention obvious.

1. Jones Patent 4,880,970 requires an expensive microprocessor (col. 3, line 66) and light color photo responsive elements 4 and 5 (col. 3, line 64) to analyze and to measure a color change (col. 3, line 61, col. 4, lines 1, 2). Jones also requires a specific complex structure as described in col. 4, lines 50 to col. 5, line 2 and shown in Figures 6 and 7 with a filter 11 and reflective surface 12 which adds to the expense.

2. Innocenti requires expensive Bragg grating reflecting elements 5 which shift color wave lengths and return the shifted wave lengths through the transmitting optical fiber when the Bragg gratings are stressed.

3. Both Jones and Innocenti measure strain locally. My invention measures volume change globally with inexpensive sensors distributed over the tank surface. DOT requires that structural integrity be checked by volume change in response to pressure. My invention provides this measurement as shown in Figures 5-26.

4. Both Jones and Innocenti require expensive equipment which is not suited for mass production and expensive color shift analyzers which are laboratory equipment and are not suited for inspecting inflation tanks in situ in aircraft and SCUBA tanks in small dive shops. Jones and Innocent signals would not correlate with volume change.

5. Neither Jones nor Innocenti nor a combination of them would have made obvious the new invention and its inexpensive manufacturing and inexpensive testing.

6. The invention is clearly separated from the prior art. Jones and Innocenti get localized readings. The present invention gets an overall reading of volume change of the tanks.

I hereby declare that all statements made herein of my own knowledge are true and that all statements made on information and belief are believed to be true, and further that these statements are made with the knowledge that willful false statements and the like so made are punishable by fine or imprisonment, or both, under Section 1001 of Title 18 of the United States Code and that such willful false statements may jeopardize the validity of the application or any patent issued thereon.

November 10, 2008

Ronald H. Knapp